Sensitivity of surface acoustic waves devices

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ABSTRACT

The Surface Acoustic Waves (SAW) devices are widely used as filters, delay lines, resonators and gas sensors. It is possible to use it as mechanical force. The paper describes sensitivity of acceleration sensor based on SAW using the Rayleigh wave propagation. Since characteristic of acceleration SAW sensors are largely determined by piezoelectric materials, it is very important to select substrate with required characteristics. Researches and numerical modeling based on simply sensor model include piezoelectric beam with unilateral free end. An aggregated mass is connected to the one. The dimension and aggregated mass are various. In this case a buckling stress and sensitivity are changed. Sensitivity in main and perpendicular axis are compare for three sensors based on SiO_2, $LiNbO_3$, $Li_2B_4O_7$. Influences of phase velocity, electro-mechanical coupling constant and density on sensitivity are investigated. Some mechanical parameters (Young's modulus, dynamic strength) of the substrates in dynamic work mode are researched using sensor model and Rayleigh model of vibrations without vibration damping. The model is useful because it simply determines dependencies between sensor parameters and substrate parameters. Differences between measured and evaluated quantities are less then 5%. Researches based on sensor models, which fulfilled mechanical specifications similarly to aircraft navigation.

Keywords: surface acoustics waves, piezoelectric crystals, acceleration sensors

1. INTRODUCTION

Reacting to the force or to the field's force is the common feature of mechanical dimension's sensors. The acceleration sensor is characterized by the simplest construction [1, 12]. There are the results of researches for the sensors, which are made as ST quartz cantilever beam, shown in that work. The converter used as SAW generator with the sensivity of 74 MHz which changes the waves by the beam's stress, is located on the beam's surface, near the fixed area. The length of its dilatory line realized with standard of 50 ohm amounts about 30 mm. The beam was 30 – 70 mm long, 3 mm wide, 1mm across. The proportion (ratio) of aggregated mass based on the free end of the beam is from 0 to 10 times. That 's the various resonance differences of beams and other various stress located in the fixing area of the generator.

Sensor's sensitivity is a parameter, which has an influence on its range of use [4,5]. The ideal sensor would react only to integrand force parallel to the axis of its sensivity. Real sensors show the sensitivity also for integrand force in prependicular axis square with the axis of main sensitivity. It reduces the accuracy of measurements. For sensors made in that way the ratio of sensitivity in the main axis is marked to the sensitivity in inclined axis.

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2. THE BEAM MODEL

To define force describing the work of beam which are possible to use the Rayleigh model is used [3]. That method requires the approximation of anizotropal mechanical ratio of the crystal, which has the cut by isotropic chosen [2]. After defining the parameters of the substitute system (Eq. 1), such as mass, energy and damping, the range of beam's work in the function of amplitude and frequency of sinusoidal force was named.
Parameters of the substitute Rayleigh system: mass, elasticy, damping and equation of motion:

$$
\begin{aligned}
m &= 0.23\rho bhl + m_s \\
k &= \frac{3E}{l^3}\frac{bh^3}{12} \\
c &= \frac{2\lambda}{T}m \\
F\sin pt &= m\frac{d^2x(t)}{dt} + c\frac{dx(t)}{dt} + kx(t)
\end{aligned}
\tag{1}
$$

where m_s - aggregated mass; ρ - mass density; b - width; h - height; l - length; E - Young modulus; λ - logarithmic damping

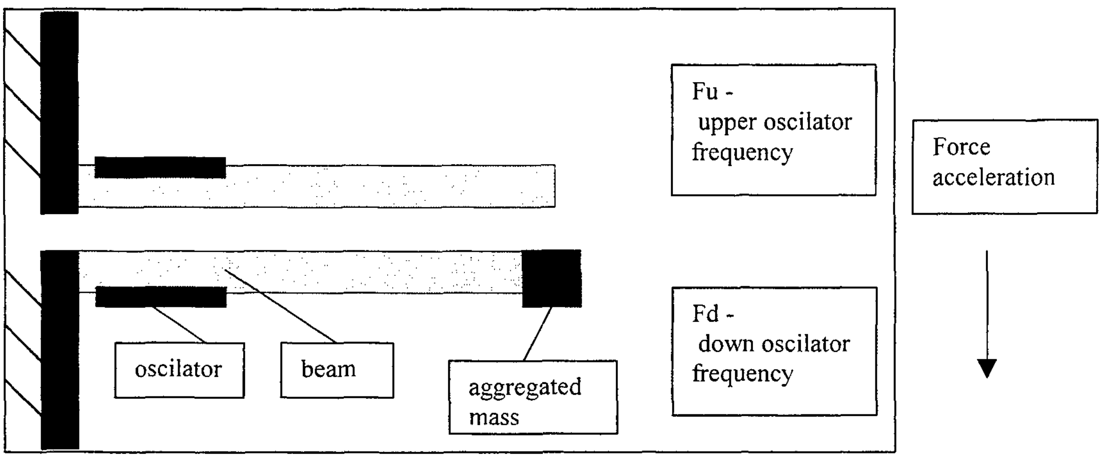

Fig. 1. Schematic view of piezoelectric beam mounted in sensor.

3. THE METHOD OF SENSITIVITY RATIO IN INCLINED AXIS TO MAIN SENSOR AXIS

The method to define the sensitivity ratio is based on:
- taking the angular SAW sensor characteristic;
- comparing the characteristics for two kinds of fixing in the starting point, the generator is supposed to be on the top and on the bottom of the beam.

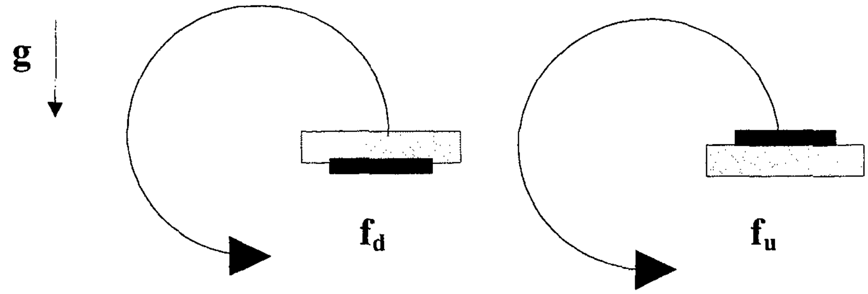

Fig. 2. View of sensor rotation in the field of Earth acceleration.

In such experiments the acceleration of gravity was defined as a force and it was treated as a constant and congeneric one [1,7]. The sensors [9] were rotated round the surface fixed by the axis of main sensitivity and one of the inclined sensitivities (longitudinal or transversal). Two kinds of fixing in the starting point were based on locating with the generator on the top and on the bottom of the beam. Received dependencies are different only because of the sign next to the coefficient of sensitivity in the main axis. Indicating the sum and difference of those expressions, there were received the dependencies containing only coefficients of the sensitivity in main or prependicular axis.
Change of oscillator frequency forced by various angles [10]

$$\Delta fu(\alpha)=A\sin(\alpha) + B\cos(\alpha)$$
$$\Delta fd(\alpha)=-A\sin(\alpha) + B\cos(\alpha) \tag{2}$$

where: A - sensivity in main axis, B - sensivity in perpendicular axis, hence analytic sum and difference of (2)

$$f(-)(\alpha) = 2A\sin(\alpha)$$
$$f(+)(\alpha) = 2B\cos(\alpha) \tag{3}$$

The difficulties of these analyses of experimental figures were based on the unacquaintance of the starting spatial orientation's angle. It consisted of beam orientation mistake in the sensor's cover, and also the mistake of sensor's fixing in the direction of the rotating surface. It causes the necessity of numerical corrections of that angle to fix its analytical dependencies to the results of the experiment as well as it possible. Dividing the values received analytically (α) by the values subsequent to analytical functions (β) the constant value of sensor's sensitivity coefficient in that axis is received. The figures 3 shows the method.

The discrete areas connected with dividing the dimensions close to 0. Their breadth is connected with the quality of numerical devise, however the symmetricalness of the decomposition is the evidence of well designated starting position of the angle.

The simplified method is based on fixing the sensitivity of SAW generator's work only in two ending positions [1]. Considerating faults which are possible to make while fixing the spatial orientation of the sample and also considerating relatively small difference read out values that method is less accurate. On the other hand it is very useful under the circumstances of dynamic force where the sensor fixing stability while lasting the experiment, is required. Sensor sensitivity in axis is connected with the cover of SAW converter (generator's frequency, its dimension). Whereas the sensitivity ratio is now a parameter characterizing the material of basement [8,9,12].

4. RESULTS

The researches were made for the amount of 16 SAW ST quartz sensors with various resonance frequency under static force circumstances. The accuracy of defining than spatial orientation's angle was about 2 grades. The average of defined sensitivity ratio was about 0,11 and its max mistake was about 3%.

For the second axis that dimension was smaller than 0,001. In consideration of fulfilled measuring devices it has not been able to show it more accurate. The researches were repeated for some dynamic forces using that simplified method. It confirmed the results of static researches. Those results including the sensitivity in main axis have been tabulated comparing to the results of D. Hauden' s work.

Tab. 1 Results of the D. Hauden and this work

Quartz ST [D. Hauden]	parameters	Quartz ST
200	length [mm]	70
10	width[mm]	5
0,5	thin[mm]	0,5
2,6	agg. mass [g]	0,5
1	(agg. mass)/(beam mass)	1
105	osc. frequency [MHz]	76
1387	**sensitivities in main axis (Hz/g)**	**~ 2000**
2,38 x 10^{-6}	**sensitivities transverse/main**	**> 0.001**
5,82 x 10^{-3}	**sensitivities compression/main**	**0.1**
5	cantilever beam res. freq. [Hz]	38
17,5	cantilever beam max. stress [MPa]	2,1

5. CONCLUSIONS

Defined value of sensitivity ratio is bigger than the figures shown in the sensor's catalogue (0 – 5%). The divergence may be caused by the fact that the figures refer to the devices containing the electronic system of characteristic correction inside. Researched sensitivities in the main axis is 2000+/-30 Hz/g and the material parameter sensitivities ratio transverse/main is 0.1 +/1 0.01. Secound sensitivities ratio is less then 0.001, but it was not possible to research it more accurancy in the fact of used measurement devices. It depends on quality of made SAW acceleration sensor.

The discussion about the difference according to D. Hauden's work can not be provided, because there are not enough sensor descriptions, which are examined in his work. However the sensitivity definition in transversal axis which is less significant than the sensitivity in longitudinal axis is the thing which is common for both of works.

To reduce the sensitivity in prependicular axis it is proposed to use two sensors in the same device, which are different from each other in the location of the generator on both sides of the beam.

The differential frequency of such a system theoretically depends only on the sensitivity in the main axis. Various parameters of the beams 30 – 70 mm long, 3 mm wide, 1mm across. The proportion (ratio) of aggregated mass based on the free end of the beam is from 0 to 10 times. That 's the various resonance differences of beams and other various stress (crytical is about 60 Mpa) located in the fixing area of the generator are showed Fig 3.

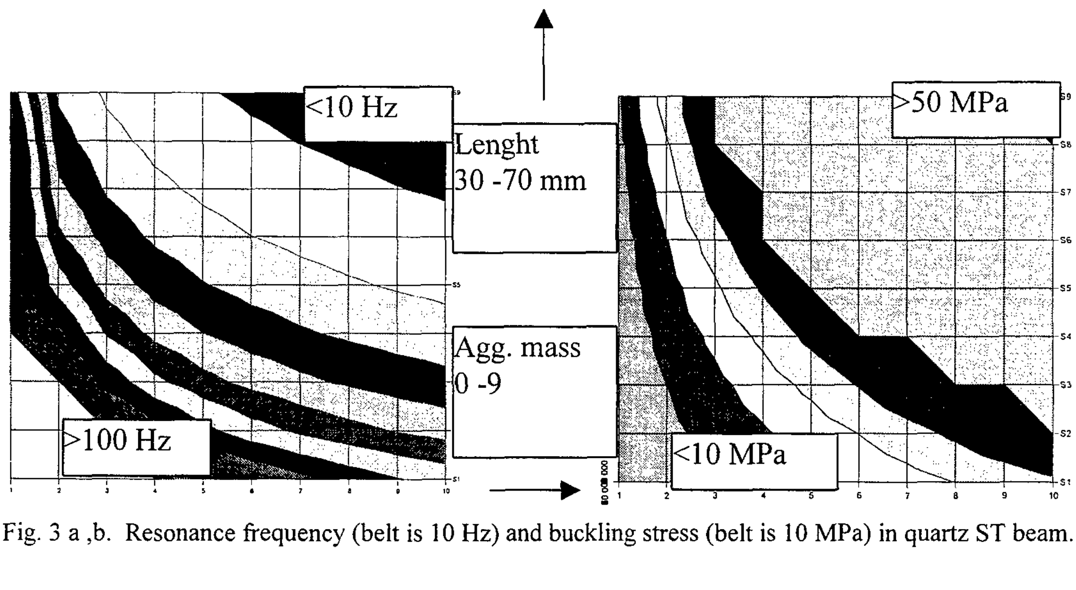

Fig. 3 a ,b. Resonance frequency (belt is 10 Hz) and buckling stress (belt is 10 MPa) in quartz ST beam.

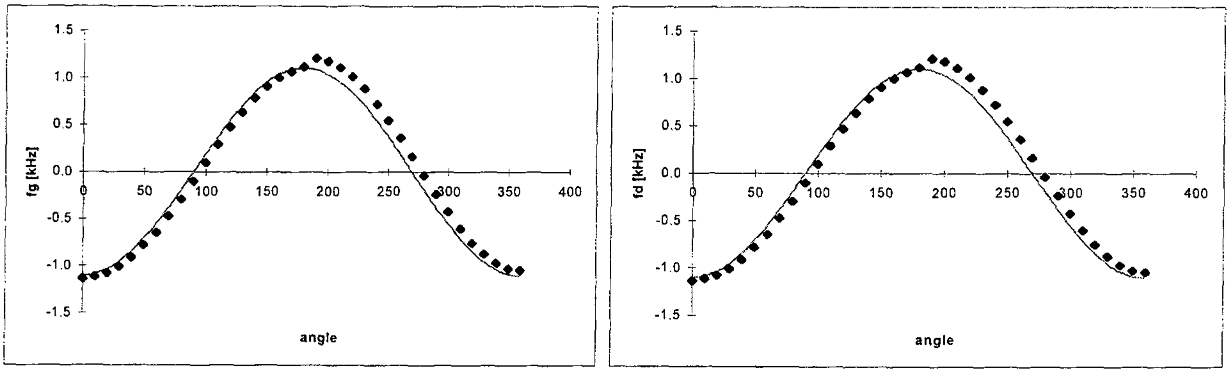

Fig. 4 a, b. Points - (experimental values) change of oscillator frequency (fu and fd), line (theoretical) **-sin**(β) function

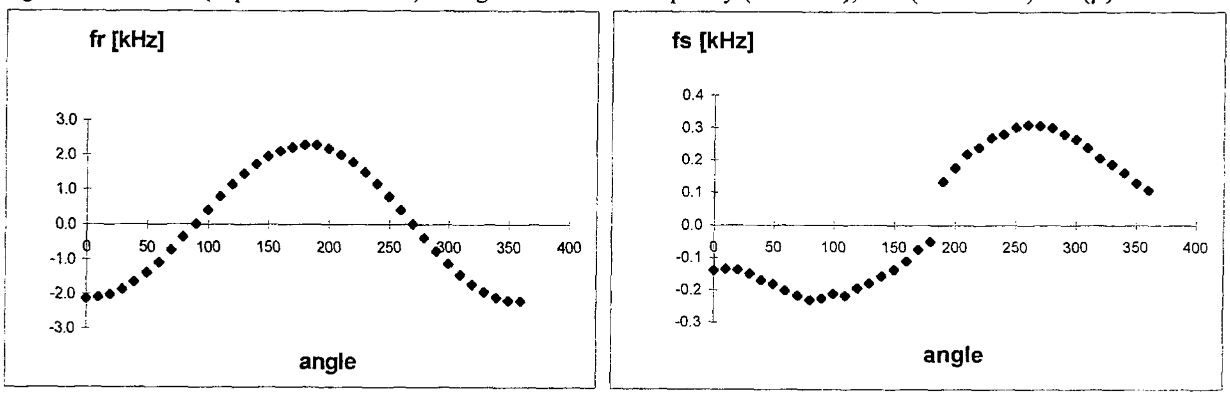

Fig. 4 c, d. Experimental f(-)(α) =2Asin(α) and f (+)(α) =2Bcos(α) from Eq. 3

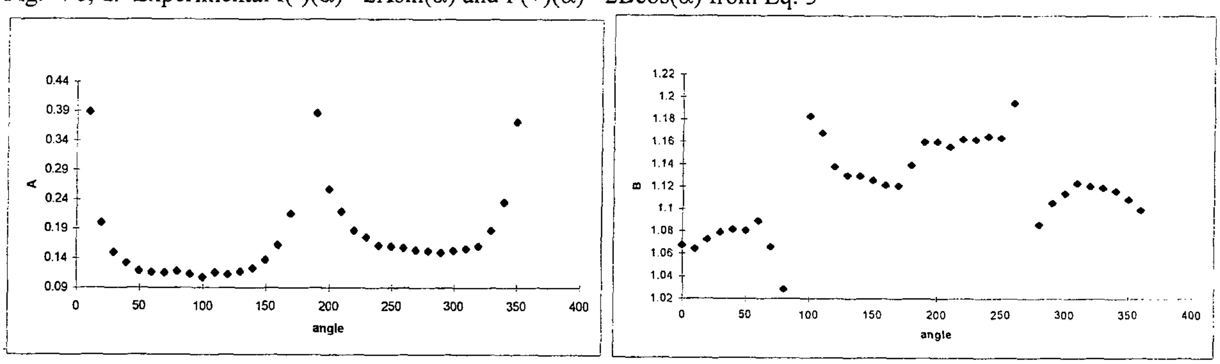

Fig. 4 e, f. Results of the 2Asin(α)/sin(β) and 2Bcos(α)/cos(β) operations

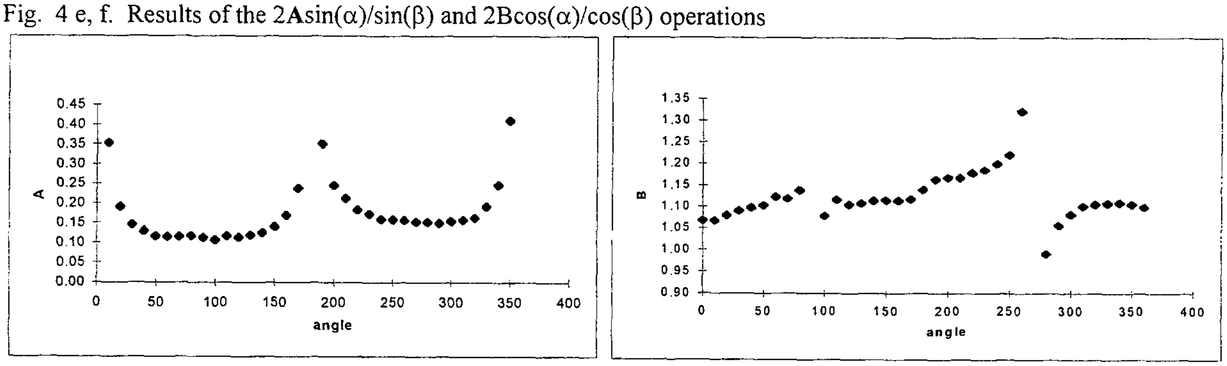

Fig. 4 g, h. Results of the 2Asin(α)/sin(β+1) and 2Bcos(α)/cos(β+1) operations

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REFERENCES

1. D. Hauden, "Elastic waves for miniaturized piezoelectric sensors: applications to physical quantity measurements and chemical detection", *Archives of Acoustics*, vol. **16** no **1**, pp. 8 - 15, 1991
2. J. F. Nye, *Physical properties of crystals, their representation by tensors and matrices,* ch. 5, PWN, Warsaw, 1962
3. S. Kaliski, *Waves and vibrations,* ch. 1, Elsevier and PWN, Warsaw, 1992
4. Litton Industries *Guidance and control systems*, catalog 10/1996
5. Sawtek Incorporated *Product catalog 1997*, http://www.sawtek.com
6. J. Filipiak, C. Kopycki, "Surface acoustic waves for the detection of small vibrations" *Sensors and Actuators*, **2435**, pp. 109-112, 1998
7. C. Kopycki, J. Filipiak, Modeling of SAW sensors sensitivity based on multiple transit signals in a delay line, *International Conference on Solid State Crystals*, pp. 229 - 232 Jurata 1998
8. J. Filipiak, L. Solarz, J. Ostrowski, C. Kopycki "Lithium niobiate as the substratum for the SAW acceleration sensor", *Solid State Crystals in Optoelectronics and Semiconductors Technology*, Proceedings SPIE 1997 - The International Society for Optical Engineering, 3179, pp. 256-260.
9. J. Filipiak, L. Solarz, C. Kopycki, K. Zubko, "Linear acceleration sensor on Surface Acoustics Waves", proceedings of the Navigation Symphosium, Air Force Institute of Technology, pp. 68-74,Warsaw 1998,
10. J. Filipiak, K. Zubko "Two dimension acceleration sensor on Surface Acoustic Waves" *proceedings of the 28 Winter School on Molecular and Quantum Acoustics*, pp. 53-56, Ustron 1999
11. K. Zubko "Lithium Tetraborate properties as a substrate for SAW acceleration sensor" *proceedings of the 28 Winter School on Molecular and Quantum Acoustics*, p. 50, Wisla 2000
12. R. Shear "Piezoelectric sensors for OEM applications", http://www.sensorsmag.com/articles/0299/oem0299/main.shtml